Appendix G
Earthquake Forces from Backfill

G-1. General

For hydraulic structures, which are able to yield laterally during an earthquake, the calculation of increased earth pressures induced by earthquakes can be approximated by the approaches outlined below. In addition, the inertial forces of the structure, plus that portion of the adjacent earth and/or water, which is assumed to act with the structure, should be included.

G-2. Mononobe-Okabe Analysis

This analysis is an extension of the Coulomb sliding-wedge theory taking into account horizontal and vertical inertial forces acting on the soil. The analysis is described in detail by Seed and Whitman (1970) and Whitman and Liao (1985).

a. Assumptions. The following assumptions are made by the Mononobe-Okabe analysis:

- The structure is free to yield sufficiently to enable full soil strength or active pressure conditions to be mobilized.
- The backfill is completely above or completely below the water table, unless the top surface is horizontal, in which case the backfill can be partially saturated.
- The backfill is cohesionless.
- The top surface is planar (not irregular or broken).
- Any surcharge is uniform and covers the entire surface of the soil wedge.
- Liquefaction is not a problem.

b. Equations. Equilibrium considerations of the soil wedge on the driving and resisting sides lead to the following Mononobe-Okabe equations for computing the active and passive forces exerted by the soil on the structure when the soil mass is at the point of failure (total shear resistance mobilized) along the slip plane of the Mononobe-Okabe wedge shown in Figure G-1:

For driving (active) wedges (Figure G-1a),

$$P_{AE} = \frac{1}{2} K_{AE} \gamma (1 - k_v) h^2 \qquad \text{(G-1)}$$

$$K_{AE} = \frac{\cos^2(\phi - \psi - \theta)}{\cos\psi \cos^2\theta \cos(\psi + \theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \psi - \beta)}{\cos(\beta - \theta)\cos(\psi + \theta + \delta)}}\right]^2} \;\; \ldots\ldots \qquad \text{(G-2)}$$

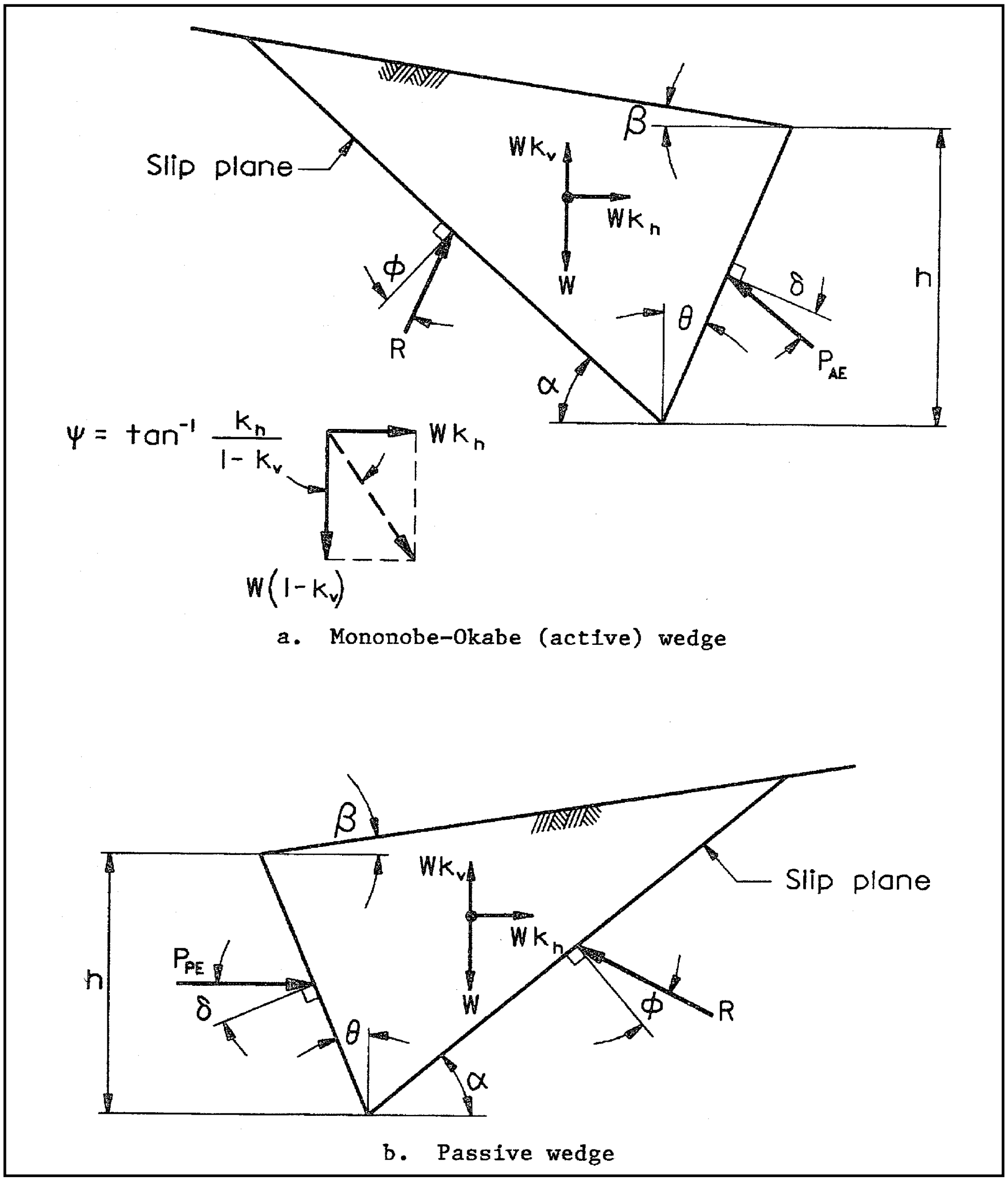


Figure G-1. Driving and resisting seismic wedges, no saturation

For resisting (passive) wedges (Figure G-1b),

$$P_{PE} = \frac{1}{2} K_{PE} \gamma (1 - k_v) h^2 \tag{G-3}$$

$$K_{PE} = \frac{\cos^2(\phi - \psi + \theta)}{\cos\psi \cos^2\theta \cos(\psi - \theta + \delta)\left[1 - \sqrt{\dfrac{\sin(\phi - \delta)\sin(\phi - \psi + \beta)}{\cos(\beta - \theta)\cos(\psi - \theta + \delta)}}\right]^2} \tag{G-4}$$

P_{AE} and P_{PE} are the combined static and dynamic forces due to the driving and resisting wedges, respectively. The equations are subject to the same limitations that are applicable to Coulomb's equations. Definitions of terms are as follows:

γ = unit weight of soil
k_v = vertical acceleration in g's
h = height of structure
ϕ = internal friction angle of soil
$\psi = \tan\left(\dfrac{k_h}{1-k_v}\right)$ = seismic inertia angle
k_h = horizontal acceleration in g's
θ = inclination of interface with respect to vertical (this definition of θ is different from θ in Coulomb's equations)
δ = soil-structure friction angle
β = inclination of soil surface (upward slopes away from the structure are positive)

c. *Simplifying Conditions*. For the usual case where k_v, δ, and θ are taken to be zero, the equations reduce to:

$$K_{AE} = \frac{\cos^2(\phi - \psi)}{\cos^2\psi\left[1 + \sqrt{\dfrac{\sin\phi\,\sin(\phi - \psi - \beta)}{\cos\beta\,\cos\psi}}\right]^2} \qquad \text{(G-5)}$$

$$K_{PE} = \frac{\cos^2(\phi - \psi)}{\cos^2\psi\left[1 - \sqrt{\dfrac{\sin\phi\,\sin(\phi - \psi + \beta)}{\cos\beta\,\cos\psi}}\right]^2} \qquad \text{(G-6)}$$

where

$\psi = \tan^{-1}(k_h)$

and

$P_{AE} = ½\, K_{AE}\, \gamma h^2$
$P_{PE} = ½\, K_{PE}\, \gamma \mathrm{h}^2$

For the case when the water table is above the backfill, P_{AE} and P_{PE} must be divided into static and dynamic components for computing the lateral forces. Buoyant soil weight is used for computing the static component below the water table, with the hydrostatic force added, and saturated soil weight is used for computing the dynamic component.

d. *Observations*. General observations from using Mononobe-Okabe analysis are as follows:

1. As the seismic inertia angle ψ increases, the values of K_{AE} and K_{PE} approach each other and, for a vertical backfill face ($\theta = 0$), become equal when $\psi = \phi$.

2. The locations of P_{AE} and P_{PE} are not given by the Mononobe-Okabe analysis. Seed and Whitman (1970) suggest that the dynamic component ΔP_{AE} be placed at the upper one-third point, ΔP_{AE} being the difference between P_{AE} and the static force from Coulomb's active wedge without the earthquake. The general wedge earthquake analysis described in paragraph G-3c places the dynamic component ΔP_{AE} at the upper one-third point, also. The latter method for computing ΔP_{AE}, which uses the same wedge for computing the static and dynamic components of

P_{AE}, is preferred.

3. The radical in the Mononobe-Okabe equation must be positive for a real solution to be possible, and for this it is necessary that $\phi \geq \psi + \beta$ for the driving wedges and $\phi \geq \psi - \beta$ for the resisting wedges. This is a limit to the horizontal acceleration coefficient for a soil wedge. The limiting condition for the driving wedge is:

$$k_h \leq (1 - k_v)\ \tan\ (\phi - \beta) \tag{G-7}$$

and for the resisting wedge:

$$k_h \leq (1 - k_v)\ \tan\ (\phi + \beta) \tag{G-8}$$

4. Figure G-2a (Applied Technology Council 1981) shows the effect on the magnification factor F_T (equal to K_{AE}/K_A) on changes in the vertical acceleration coefficient k_v. Positive values of k_v have a significant effect for values of k_v greater than 0.2. The effect is greater than 10 percent above and to the right of the dashed line. For values of k_h of 0.2 or less, k_v can be neglected for all practical purposes.

5. K_{AE} and F_T are also sensitive to variations in backfill slope, particularly for higher values of horizontal acceleration. This effect is shown in Figure G-2b.

G-3. General Wedge Earthquake Analysis

For many projects, all the Coulomb wedge assumptions are met, and the following wedge analysis should be used. The equations for the dynamic force given below for various conditions are simply the horizontal acceleration coefficient multiplied by the weight of the wedge defined by the critical slip-plane angle. See the example later in this chapter for more information.

a. Assumptions. The equations for determining the critical slip-plane angle for driving and resisting wedges subjected to a horizontal acceleration are developed with the following assumptions:

(1) The shear on the vertical face of the wedge is zero.

(2) The shear strength along the potential slip planes in the soil has not been mobilized to any extent, i.e., for static loading prior to an earthquake.

b. Equations for Cohesionless, Dry Backfill Above the Water Table. Driving and resisting forces for cohesionless, dry, sloping planar-surfaced backfill below the water table where k_v, δ, and $\theta = 0$ can be computed as follows:

(1) Static Components. The static components for a driving and resisting wedge are:

$$P_A = \frac{1}{2} K_A\, \gamma\, h^2 \tag{G-9}$$

$$P_P = \frac{1}{2} K_P\, \gamma\, h^2 \tag{G-10}$$

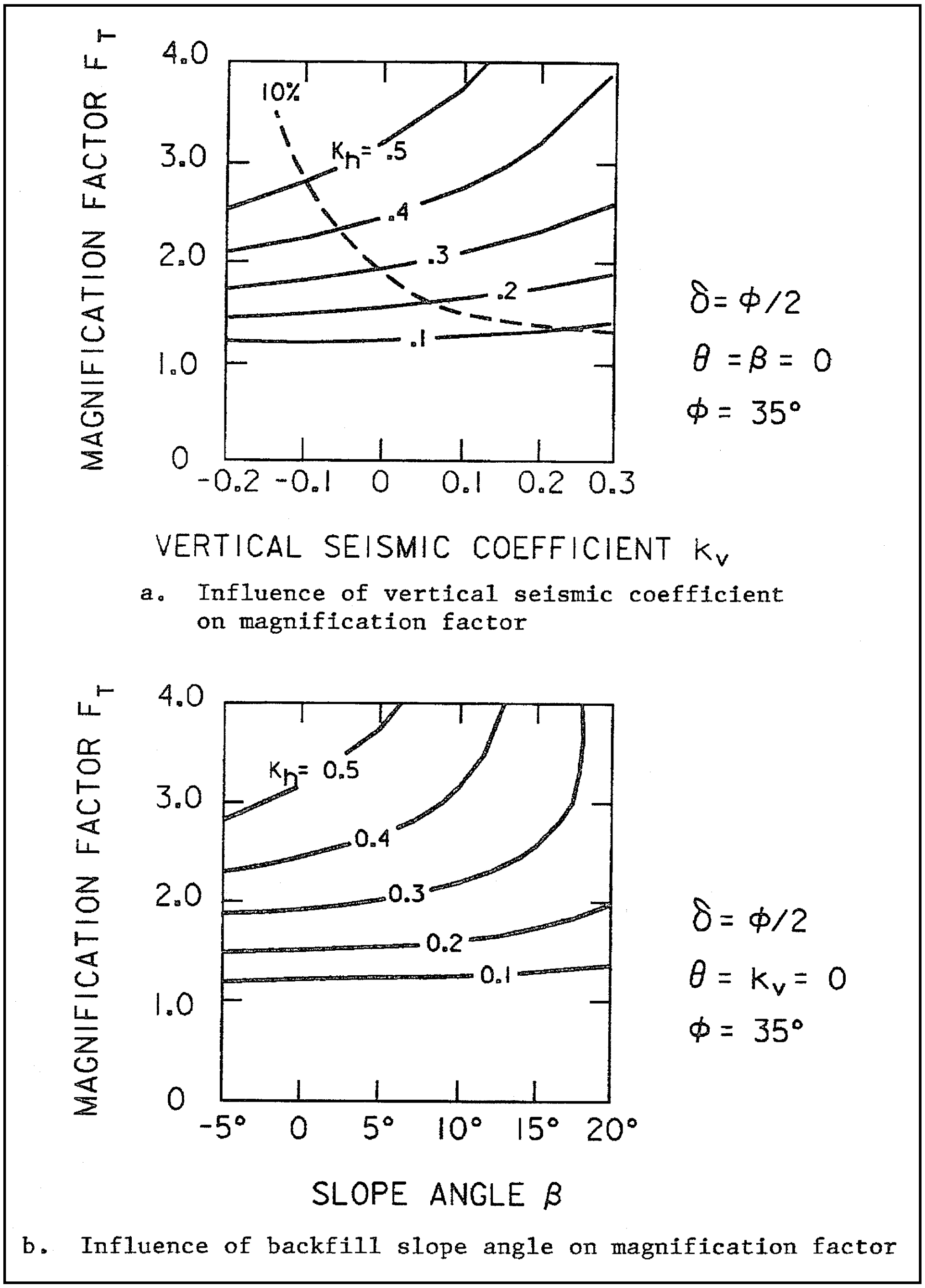


Figure G-2. Influence of k_v and β on magnification factor (after Applied Technology Council 1981)

where

$$K_A = \left(\frac{1 - \tan\phi \cot\alpha}{1 + \tan\phi \tan\alpha}\right)\left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right) \tag{G-11}$$

$$K_P = \left(\frac{1 + \tan\phi \cot\alpha}{1 - \tan\phi \tan\alpha}\right)\left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right) \tag{G-12}$$

For an active wedge:

$$\alpha = \tan^{-1}\left(\frac{c_1 + \sqrt{c_1^2 + 4c_2}}{2}\right) \tag{G-13}$$

$$c_1 = \frac{2\,(\tan\phi - k_h)}{1 + k_h\,\tan\phi} \tag{G-14}$$

$$c_2 = \frac{\tan\phi\,(1 - \tan\phi\,\tan\beta) - (\tan\beta + k_h)}{\tan\phi\,(1 + k_h\,\tan\phi)} \tag{G-15}$$

For a passive wedge:

$$\alpha = \tan^{-1}\left(\frac{-c_1 + \sqrt{c_1^2 + 4c_2}}{2}\right) \tag{G-16}$$

$$c_1 = \frac{2\,(\tan\phi - k_h)}{1 + k_h\,\tan\phi} \tag{G-17}$$

$$c_2 = \frac{\tan\phi(1 + \tan\phi\tan\beta) + (\tan\beta - k_h)}{\tan\phi(1 + k_h\tan\phi)} \tag{G-18}$$

If $k_v > 0$, replace γ with $(1 - k_v)\,\gamma$ and replace k_h with $\tan\psi$ or with $k_h/(1-k_v)$.

(2) Dynamic Components. The dynamic component for each wedge is:

$$\Delta P_{AE} = \Delta P_{PE} = k_h\left[\frac{\gamma h^2}{2\,(\tan\alpha - \tan\beta)}\right]$$

If $k_v > 0$, replace k_h with $k_h - k_v \tan(\alpha-\phi)$. (G-19)

(3) Total Driving Force. The total driving force is:

$$P_{AE} = P_A + \Delta P_{AE} \tag{G-20}$$

Equation G-21 was deleted. (G-21)

The line of action for P_{AE} may be found as:

$$Y_{AE} = \frac{P_A \left(\frac{h}{3}\right) + \Delta P_{AE} \left(\frac{2h}{3}\right)}{P_{AE}} \tag{G-22}$$

It should be noted that values of k_h cannot exceed the limit in equation (G-7).

(4) Total Resisting Force. The total resisting force is:

$$P_{PE} = P_P - \Delta P_{PE} \tag{G-23}$$

equation G-24 was deleted. (G-24)

The line of action for P_{PE} may be found as:

$$Y_{PE} = \frac{P_P \left(\frac{h}{3}\right) - \Delta P_{PE} \left(\frac{2h}{3}\right)}{P_{PE}} \tag{G-25}$$

c. Equations for Cohesionless Backfill with Water Table. Driving and resisting forces for cohesionless, sloping, planar-surfaced backfill with water table where k_v, δ and θ = 0 can be computed as follows:

(1) Driving Force. The static components for a driving wedge are (see Figures G-3a and G-4a):

$$P_A = P_{A1} + P_{A2} = \frac{1}{2} K_A \gamma (h - h_s)^2 + \frac{1}{2} h_s \left[2K_A \gamma (h - h_s) + K_b \gamma_b h_s \right] \tag{G-26}$$

$$P_{ws} = \frac{1}{2} \gamma_w h_s^2 \tag{G-27}$$

and the dynamic components are (see Figures G-3a and G-4a):

$$\Delta P_{AE} = \Delta P_{AE1} + \Delta P_{AE2} = k_h \left[\frac{\gamma h^2}{2 (\tan \alpha - \tan \beta)} \right] + k_h \left[\frac{(\gamma_s - \gamma) h_s^2}{2 \tan \alpha} \right] \tag{G-28}$$

giving a total force of:

$$P_{AE} = P_A + P_{ws} + \Delta P_{AE} \tag{G-29}$$

where

γ_s = saturated unit weight of fill
γ = moist unit weight of fill
γ_b = buoyant unit weight of fill
γ_w = unit weight of water

$$K_A = \left(\frac{1 - \tan\phi\cot\alpha}{1 + \tan\phi\tan\alpha}\right)\left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right)$$

$$K_b = \left(\frac{1 - \tan\phi\cot\alpha}{1 + \tan\phi\tan\alpha}\right)\left[1 + \left(\frac{\tan\alpha}{\tan\alpha - \tan\beta} - 1\right)\frac{\gamma}{\gamma_b}\right]$$

and α is defined in Equation G-13.

(2) Resisting Force. The static components for the resisting wedge are (see Figures G-3b and G-4b):

$$P_P = P_{P1} + P_{P2} = \frac{1}{2}K_P\gamma(h - h_s)^2 + \frac{1}{2}h_s\left[2K_P\gamma(h - h_s) + K_b\gamma_b h_s\right] \tag{G-30}$$

$$P_{ws} = \frac{1}{2}\gamma_w h_s^2 \tag{G-31}$$

and the dynamic components are:

$$\Delta P_{PE} = \Delta P_{PE1} + \Delta P_{PE2} = k_h\left[\frac{\gamma h^2}{2(\tan\alpha - \tan\beta)}\right] + k_h\left[\frac{(\gamma_s - \gamma)h_s^2}{2\tan\alpha}\right] \tag{G-32}$$

giving a total force of:

$$P_{PE} = P_P + P_{ws} - \Delta P_{PE} \tag{G-33}$$

where γ, γ_b, γ_s, and γ_w are defined in paragraph G-3b(3),

and

$$K_P = \left(\frac{1 + \tan\phi\cot\alpha}{1 - \tan\phi\tan\alpha}\right)\left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right) \tag{G-34}$$

$$K_b = \left(\frac{1 + \tan\phi\cot\alpha}{1 - \tan\phi\tan\alpha}\right)\left[1 + \frac{\tan\alpha}{\tan\alpha - \tan\beta} - 1\,\frac{\gamma}{\gamma_b}\right] \tag{G-35}$$

and the equations for α are given in Equation G-16.

d. Equations for Cohesive Backfill with Water Table. Driving and resisting forces for a cohesive, sloping, planar-surfaced backfill with water table where k_v, δ, and $\theta = 0$ can be computed as follows:

(1) Driving Force. The static components for the driving wedge are (see Figure G-5a):

$$P_A = P_{A1} + P_{A2} = \frac{1}{2} K_A \gamma \left[(h - d_c) - h_s \right]^2 + \frac{1}{2} h_s \left[2K_A \gamma (h - d_c - h_s) + K_b \gamma_b h_s \right] \tag{G-36}$$

$$P_{ws} = \frac{1}{2} \gamma_w h_s^2 \tag{G-37}$$

and the dynamic components are (see Figure G-5a):

$$\Delta P_{AE} = \Delta P_{AE1} + \Delta P_{AE2} = k_h \left[\frac{\gamma (h^2 - d_c^2)}{2 (\tan \alpha - \tan \beta)} \right] + k_h \left[\frac{(\gamma_s - \gamma)^2 h_s^2}{2 \tan \alpha} \right] \tag{G-38}$$

giving a total force of:

$$P_{AE} = P_A + P_{ws} + \Delta P_{AE} \tag{G-39}$$

where

γ = moist unit weight of fill
γ_b = buoyant unit weight of fill
γ_s = saturated unit weight of fill
γ_w = unit weight of water

$$K_A = \left(\frac{1 - \tan \phi \cot \alpha}{1 + \tan \phi \tan \alpha} \right) \left(\frac{\tan \alpha}{\tan \alpha - \tan \beta} \right) \tag{G-40}$$

$$K_b = \left(\frac{1 - \tan \phi \cot \alpha}{1 + \tan \phi \tan \alpha} \right) \left[1 + \left(\frac{\tan \alpha}{\tan \alpha - \tan \beta} - 1 \right) \frac{\gamma}{\gamma_b} \right] \tag{G-41}$$

$$\alpha = \tan^{-1} \left(\frac{c_1 + \sqrt{c_1^2 + 4c_2}}{2} \right) \tag{G-42}$$

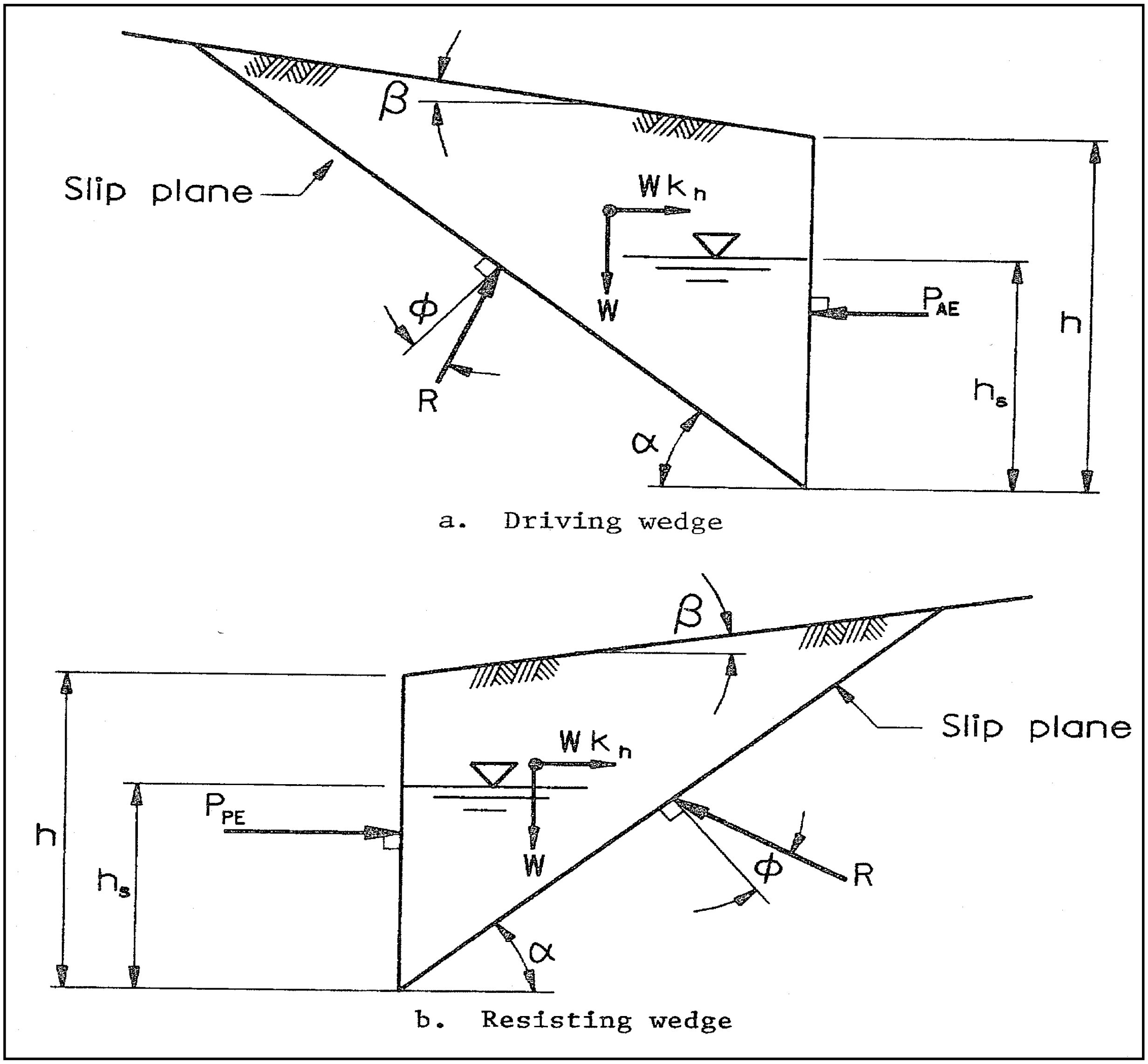


Figure G-3. Seismic wedges, water table within wedge

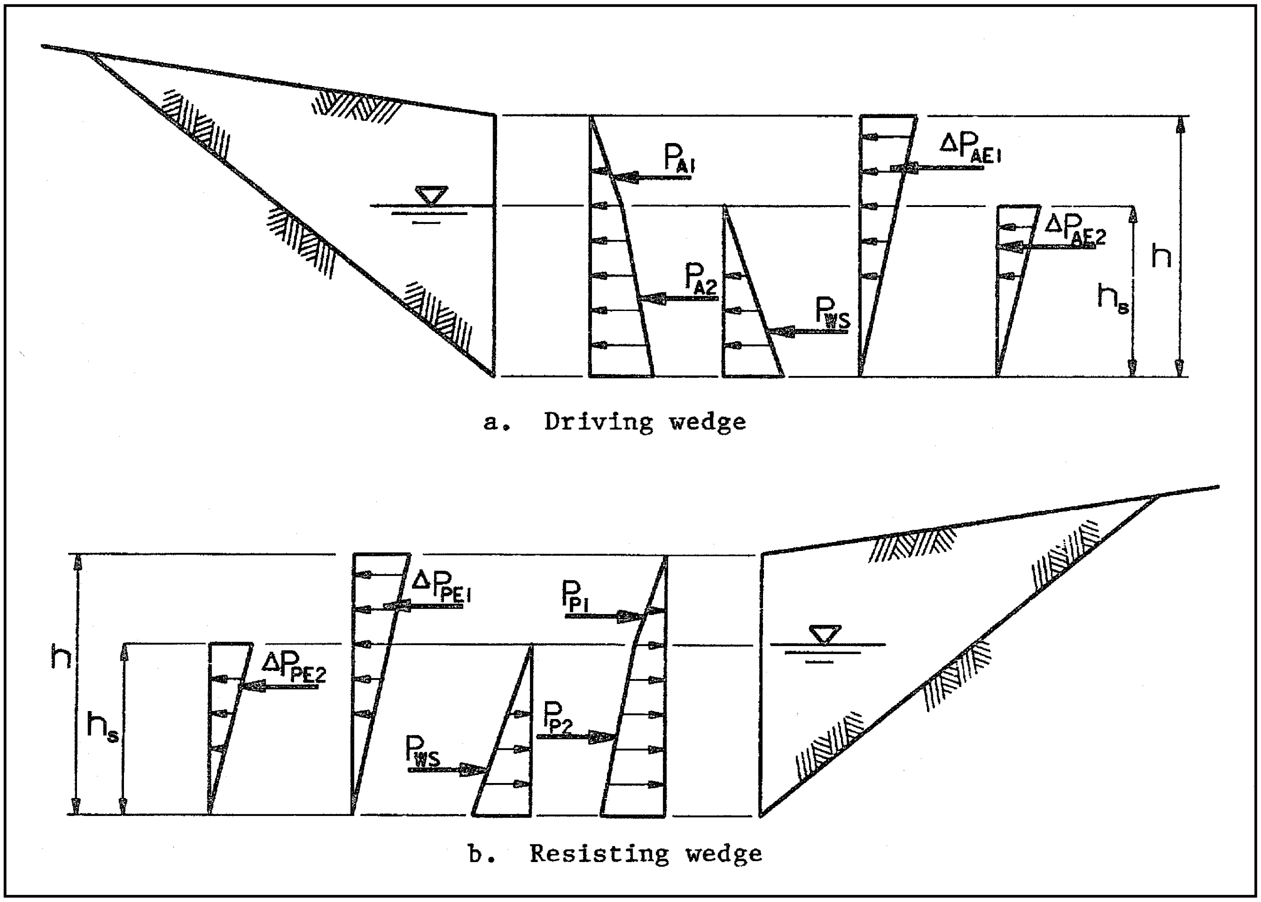


Figure G-4. Static and dynamic pressure diagrams, water table within wedge

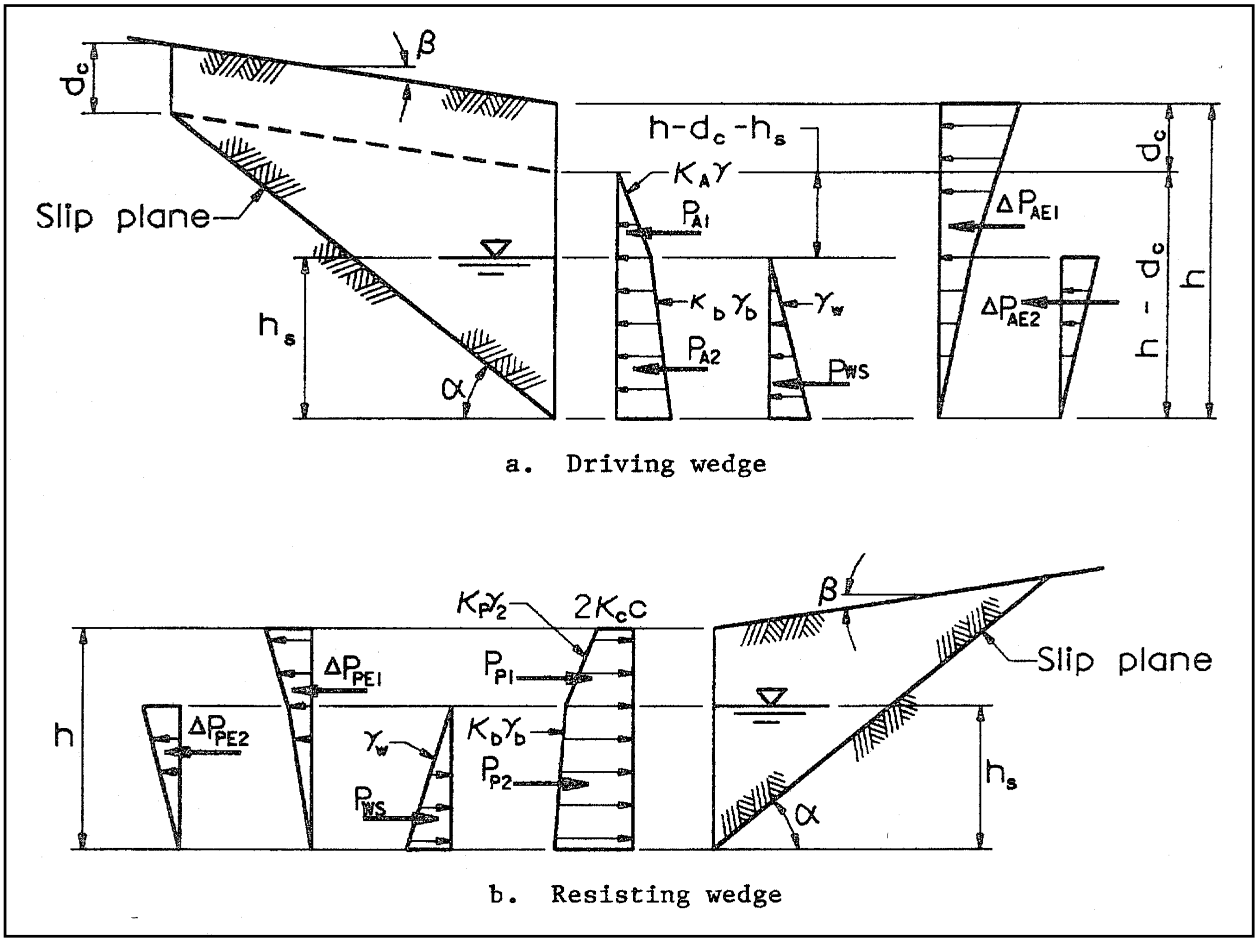


Figure G-5. Static and dynamic pressure diagrams, cohesive fill, water table within wedge

$$c_1 = \frac{2\tan\phi\,(\tan\phi - k_h) + \dfrac{4c\,(\tan\phi + \tan\beta)}{\gamma(h + d_c)}}{A} \tag{G-43}$$

$$c_2 = \frac{\tan\phi\,(1 - \tan\phi\tan\beta) - (\tan\beta + k_h) + \dfrac{2c\,(1 - \tan\phi\tan\beta)}{\gamma(h + d_c)}}{A} \tag{G-44}$$

$$A = (1 + k_h\tan\phi)\tan\phi + \frac{2c\,(1 - \tan\phi\tan\beta)}{\gamma(h + d_c)} \tag{G-45}$$

$$d_c = \frac{c/\gamma}{\cos\alpha\,(\sin\alpha - \tan\phi\cos\alpha)} \tag{G-46}$$

(2) Resisting Force. The static components for the resisting wedge are (Figure G-5b):

$$P_P = P_{P1} + P_{P2} = \frac{1}{2} K_P \gamma (h - h_s)^2 + \frac{1}{2} h_s \left[2K_P \gamma (h - h_s) + K_b \gamma_b h_s \right] + 2K_c ch \quad \text{(G-47)}$$

$$P_{ws} = \frac{1}{2} \gamma_w h_s^2 \quad \text{(G-48)}$$

and the dynamic components are (see Figure G-5b):

$$\Delta P_{PE} = \Delta P_{PE1} + \Delta P_{PE2} = k_h \left[\frac{\gamma h^2}{2 (\tan \alpha - \tan \beta)} \right] + k_h \left[\frac{(\gamma_s - \gamma) h_s^2}{2 \tan \alpha} \right] \quad \text{(G-49)}$$

giving a total force of:

$$P_{PE} = P_P + P_{ws} + \Delta P_{PE} \quad \text{(G-50)}$$

where γ, γ_b, γ_s, and γ_w are defined in paragraph 3-26c(4)(a), and

$$K_P = \left(\frac{1 + \tan \phi \cot \alpha}{1 - \tan \phi \tan \alpha} \right) \left(\frac{\tan \alpha}{\tan \alpha - \tan \beta} \right) \quad \text{(G-51)}$$

$$K_b = \left(\frac{1 + \tan \phi \cot \alpha}{1 - \tan \phi \tan \alpha} \right) \left[1 + \left(\frac{\tan \alpha}{\tan \alpha - \tan \beta} - 1 \right) \frac{\gamma}{\gamma_b} \right] \quad \text{(G-52)}$$

$$\alpha = \tan^{-1} \left(\frac{-c_1 + \sqrt{c_1^2 + 4c_2}}{2} \right) \quad \text{(G-53)}$$

$$c_1 = \frac{2 \tan \phi (\tan \phi - k_h) + \dfrac{4c (\tan \phi - \tan \beta)}{\gamma h}}{A} \quad \text{(G-54)}$$

$$c_2 = \frac{\tan \phi (1 + \tan \phi \tan \beta) + (\tan \beta - k_h) + \dfrac{2c (1 + \tan \phi \tan \beta)}{\gamma h}}{A} \quad \text{(G-55)}$$

$$A = (1 + k_h \tan \phi) \tan \phi + \frac{2c (1 + \tan \phi \tan \beta)}{\gamma h} \quad \text{(G-56)}$$

$$K_c = \frac{1}{2 \sin \alpha \cos \alpha \,(1 - \tan \phi \cos \alpha)} \cdot \frac{\tan \alpha}{\tan \alpha - \tan \beta} \qquad \text{(G-57)}$$

G-4. Inertia Force of Structure

The inertia force of the structure, including that portion of the backfill above the heel or toe of the structure and any water within the backfill which is not included as part of the backfill wedge, is computed by multiplying the selected acceleration coefficient by the weight of the structure and backfill. This force is obtained by multiplying the mass by the acceleration coefficient.

G-4. Selection of Acceleration Coefficients

a. Minimum Acceleration Coefficients. Preliminary estimates of horizontal acceleration coefficient values are listed in Table G-1. The seismic zone designations used in this table are defined in ER 1110-2-1806. These values can be used to determine if the lateral earthquake forces control the stability of structures. The vertical acceleration coefficient should be estimated as two-thirds of the horizontal acceleration coefficient. If failure of the structure would jeopardize the safety of a dam, then the acceleration coefficients should be consistent with those used for the stability analyses and concrete design of the dam.

Table G-1 Minimum Seismic Horizontal Acceleration Coefficients

Zone	Coefficient
0	0.00
1	0.05
2A, 2B	0.10
3	0.15
4	0.20

b. Acceleration Coefficients Greater than 0.2. If the design acceleration coefficient exceeds 0.2, a wedge method of seismic analysis may be excessively conservative, and a permanent displacement or a dynamic soil-structure interaction analysis should be performed. A method for computing the magnitude of relative structure displacement during a specified earthquake is described by Whitman and Liao (1985). The dynamic soil pressures and associated forces in the backfill may be analyzed as an elastic response using Wood’s method as described in Ebeling and Morrison (1992).

G-5. Example

a. Problem definition.

Soil properties (on both sides of structure):

$\gamma = 0.12$ k/ft^3 (moist weight)
$\gamma_b = 0.0625$ k/ft^3 (buoyancy weight)
$\gamma_s = 0.125$ k/ft^3 (saturated weight)
$\phi = 35°$, $c = 0$

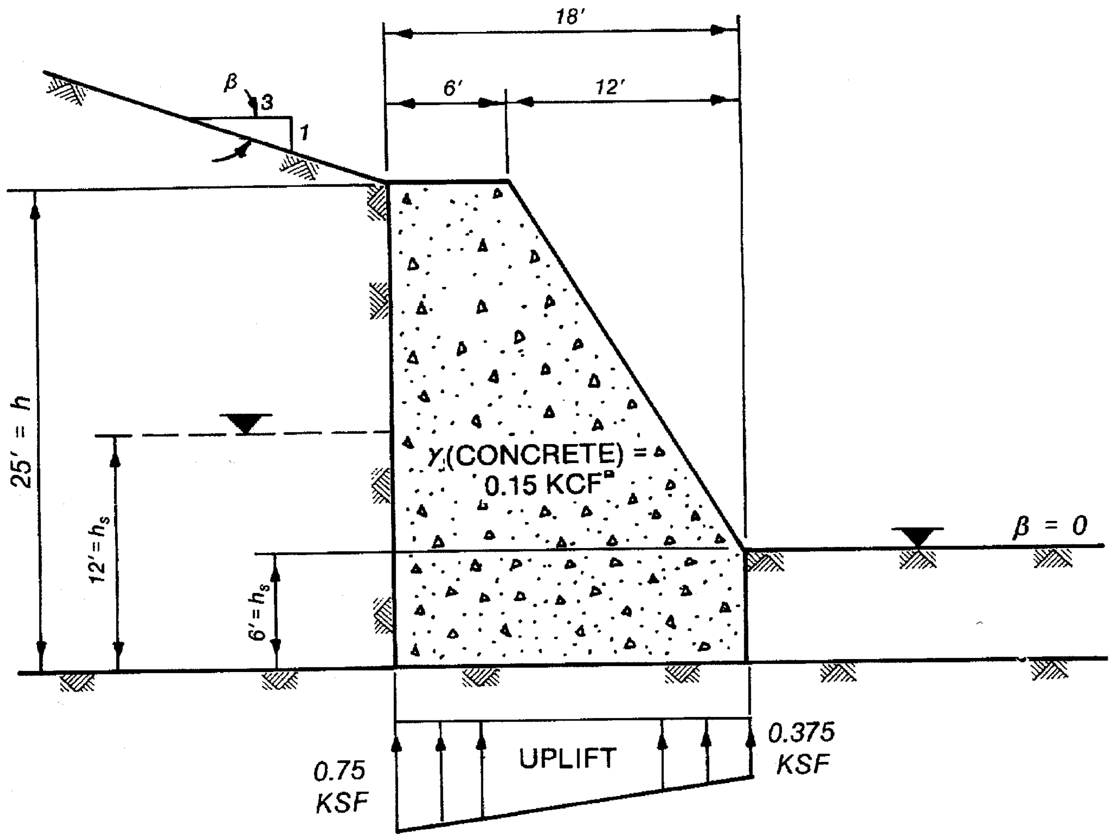
Seismic coefficients:

$k_H = 0.20$
$k_v = 0$

b. Find forces acting on driving side.

$$c_1 = \frac{2\,(\tan\phi - k_h)}{1 + k_h\,\tan\phi} = \frac{2(0.700208 - 0.2)}{1 + 0.2(0.700208)} = 0.877526 \qquad \text{(G-)}$$

$$c_2 = \frac{\tan\phi\,(1 - \tan\phi\,\tan\beta) - (\tan\beta + k_h)}{\tan\phi\,(1 + k_h\,\tan\phi)} \qquad \text{(G-)}$$



$$c_2 = \frac{0.700208\left(1 - 0.700208 \times \frac{1}{3}\right) - \left(\frac{1}{3} + 0.2\right)}{0.700208\,(1 + 0.2 \times 0.700208)} = 0.004315 \qquad \text{(G-)}$$

$$\alpha = \tan^{-1}\left(\frac{c_1 + \sqrt{c_1^2 + 4c_2}}{2}\right) = \underline{\underline{41.426°}} \qquad \text{(G-)}$$

$$K = \frac{1 - \tan\phi \cot\alpha}{1 + \tan\phi \tan\alpha)} = \frac{1 - 0.700208(1.133240)}{1 + 0.700208(0.882425)}$$

$$K = 0.12763$$

$$K_A = K\left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right) = 0.12763\left(\frac{0.882425}{0.882425 - \frac{1}{3}}\right) = \underline{\underline{0.2051}} \qquad \text{(G-)}$$

$$K_b = K\left[1 + \left(\frac{\tan\alpha}{\tan\alpha - \tan\beta}\right) - 1\left(\frac{\gamma}{\gamma_b}\right)\right] \quad \text{(see Appendix H)}$$

$$K_b = 0.12763\left[1 + \left(\frac{0.882425}{0.549092} - 1\right)\left(\frac{0.12}{0.0625}\right)\right] = \underline{\underline{0.2764}}$$

$$P_A = \frac{1}{2}K_A\gamma(h - h_s)^2 + \frac{1}{2}(h_s)\left[2K\gamma(h - h_s) + K_b\gamma_b h_s\right] \qquad \text{(G-)}$$

$$P_A = \frac{1}{2}(0.2051)(0.12)(13)^2 + \frac{1}{2}(12)\left[2(0.2051)(0.12)(13) + 0.2764(0.0625)(12)\right]$$

$$P_A = \underline{\underline{7.16\ k}}$$

$$\Delta P_{AE} = k_h\left[\frac{\gamma h^2}{2(\tan\alpha - \tan\beta)} + \frac{(\gamma_s - \gamma)h_s^2}{2\tan\alpha}\right] \qquad \text{(G-)}$$

$$\Delta P_{AE} = 0.2\left[\frac{0.12(25)^2}{2(0.549092)} + \frac{0.005(12)^2}{2(0.882425)}\right] = \underline{\underline{13.74\ k}}$$

$$P_{ws} = \frac{1}{2}\gamma_w h_s^2 = \frac{1}{2}(0.0625)(12)^2 = \underline{\underline{4.50\ k}} \qquad \text{(G-)}$$

c. Find forces acting on resisting side.

$$c_1 = \frac{2(\tan\phi - k_h)}{1 + k_h\tan\phi} = \frac{2(0.700208 - 0.2)}{1 + 0.2(0.700208)} = 0.877526 \qquad \text{(G-)}$$

From equation G-18

$$c_2 = \frac{\tan\phi - k_h}{\tan\phi\,(1 + k_h\ \tan\phi)}$$

$$c_2 = \frac{0.700208 - 0.2}{0.700208(1 + 0.2 \times 0.700208)} = \underline{\underline{0.626618}}$$

$$\alpha = \tan^{-1}\left(\frac{-c_1 + \sqrt{c_1^2 + 4c_2}}{2}\right) = \underline{\underline{24.999^\circ}} \qquad \text{(G-)}$$

From Equation G-34

$$K_P = \frac{1 + \tan\phi\ \cot\alpha}{1 - \tan\phi\ \tan\alpha)} = \frac{1 + 0.700208(2.144605)}{1 - 0.700208(0.466286)}$$

$$K_P = \underline{\underline{3.7144}}$$

From Equation G-30

$$P_P = \frac{1}{2}\,K_P\,\gamma_b\,h^2 = \frac{1}{2}\,(3.7144)(0.0625)(6)^2 = \underline{\underline{4.18\ k}}$$

From Equation G-32

$$\Delta P_{PE} = k_h\left(\frac{\gamma_s\,h^2}{2\ \tan\alpha}\right) = 0.2\left[\frac{0.125(6)^2}{2(0.466286)}\right] = \underline{\underline{0.97\ k}}$$

$$P_{ws} = \frac{1}{2}\ \gamma_w\,h_s^{\,2} = \frac{1}{2}\,(0.0625)(6)^2 = \underline{\underline{1.13\ k}} \qquad \text{(G-)}$$

d. Find inertia force due to weight of structure.

$$18' \times 25' \times 0.15 = 67.50 \times 12.50' = 843.75$$

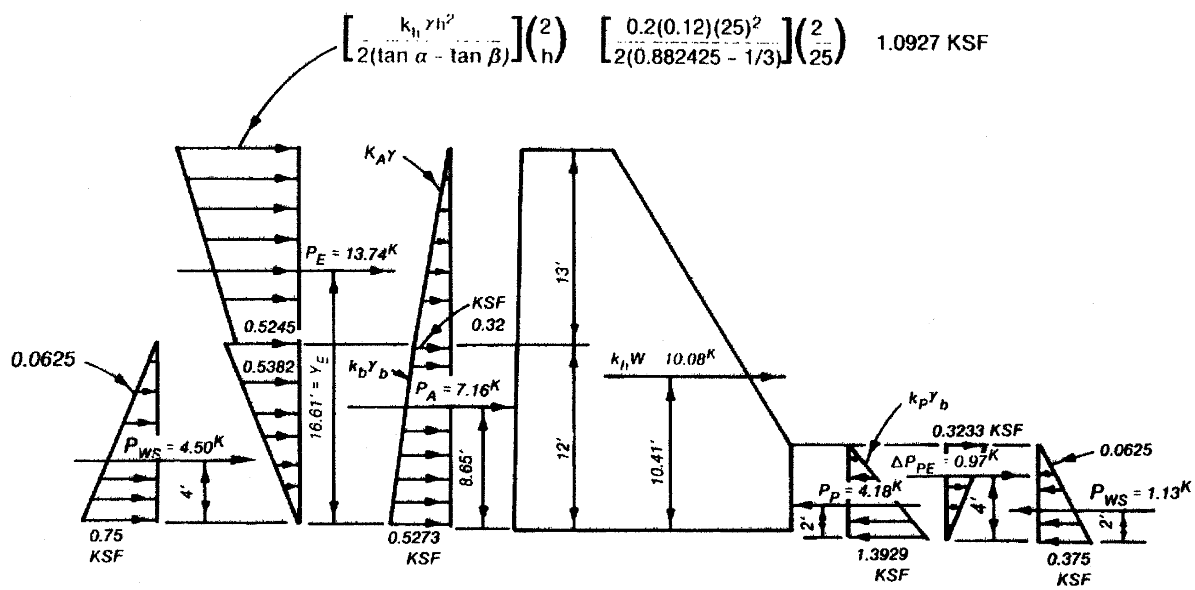
$$-\frac{1}{2} \times 12' \times 19' \times 0.15 = \underline{-17.10} \times 18.67' = \underline{-319.25}$$

$$W = 50.40\ k \qquad\qquad 524.50$$

$$\bar{y} = \frac{524.50}{50.40} = \underline{\underline{10.41\ ft}}$$

$$k_h W = 0.2(50.40\ k) = \underline{\underline{10.08\ k}}$$

e. Summary of forces and pressure distributions.



(1) Permissible simplification for dynamic earth pressure distribution—driving side. The discontinuity of this pressure diagram, at the water table, may be eliminated by considering that the soil weight above and below water is equal to the moist weight. The difference is not significant. In this case, the difference in forces is -0.58% and difference in dimension, Y_E, is +0.36%.

(2) Mononobe-okabe force and pressure distribution--resisting side. If the pressure diagrams for P_P and ΔP_{PE} (on the preceding page) are combined, negative pressure will be obtained for some distance below the top of ground. Since earth pressure cannot pull on the structure, the pressure diagram and force should be determined by setting all negative pressures to zero.